# A Fundamental and Technical Review of Radomes

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The basic function of a radome is to form a protective cover between an antenna and the environment with minimal impact to the electrical performance of the antenna. Under ideal conditions a radome is electrically invisible. How well a radome accomplishes this depends on matching its configuration and materials composition to a particular application and RF frequency range.

Radomes can be found protecting a wide range of outdoor terrestrial and shipboard communications systems and radar installations as well as airborne avionics system antennas. The proper selection of a radome for a given antenna can actually help improve overall system performance, by:

1. Maintaining alignment by eliminating wind loading;
2. Allowing for all-weather operation by protecting the system from rain, snow, hail, sand, salt spray, insects, animals, UV damage, and wide temperature fluctuations;
3. Providing shelter for installation and maintenance personnel;
4. Preventing visual observation of system (security); and
5. Minimizing downtime, and extending component and system operating life.

Historically, a variety of materials have been used for constructing radomes, including balsa and plywood in early structures. Modern ground-based and ship-based radomes are manufactured using composite materials such as fiberglass, quartz, and aramid fibers held together with polyester, epoxy, and other resins [1] such as the one shown in Figure 1. Foam and honeycomb cores are often added between inner and outer “skins” of the radome to function as a low-dielectric-constant spacer material providing structural strength and rigidity.

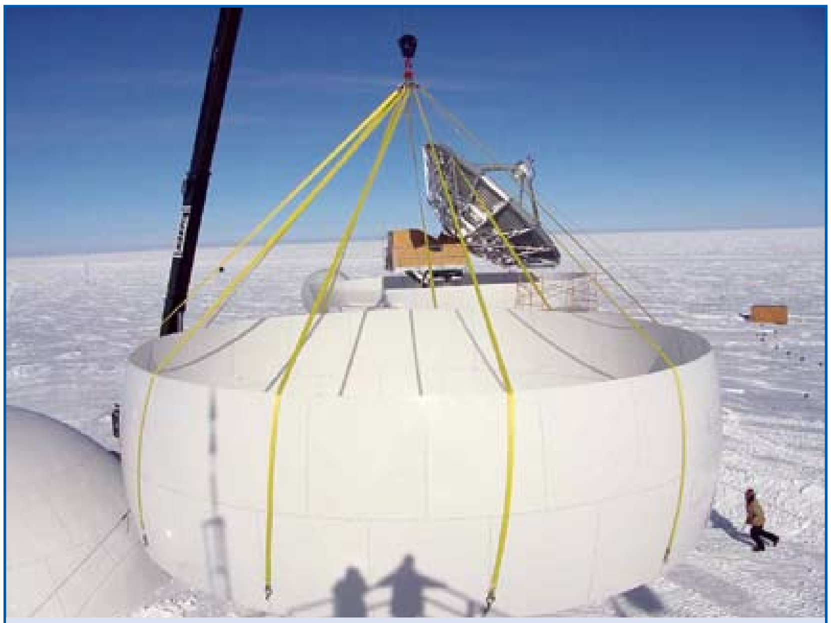

*Figure 1: MFG Galileo composite radome during installation at the South Pole for a satellite communication system.*

It is important that the dielectric constant of the material is low. A low dielectric constant material reduces reflections. Reduced reflections minimize impact to the radiation pattern and insertion loss. Some materials such as UHMWPE and many plastics have a dielectric constant close to 2. However, requirements such as high strength, high operating temperature, or low cost preclude them in many cases.

## Understanding RF Reflections

Radomes are generally made of dielectric materials which are characterized by their dielectric constant, loss tangent, and various other electrical parameters. Dielectric materials have a characteristic impedance of

$$Z_D = \frac{377\Omega}{\sqrt{\varepsilon_r}}$$

where $\varepsilon_r$ is the dielectric constant relative to free space. The impedance of free space is

$$Z_B = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega .$$

When an electromagnetic wave in free space impinges upon a dielectric material at normal incidence as shown in Figure 2, the reflection coefficient is

$$\Gamma = \frac{Z_D - Z_B}{Z_D + Z_B} .$$

Since $Z_D$ is less than $Z_B$, the reflection coefficient $\Gamma$ is negative which means reflected wave is 180° out of phase with the incident wave. When the wave hits the free space boundary on the other side of the dielectric, the numerator reverses and $\Gamma = \frac{Z_B - Z_D}{Z_D + Z_B}$ . [2]

## Radome Configurations

Several radome configurations are used to minimize RF reflections, including electrically thin, half-wave, A-sandwich, C-sandwich and others [3]. The best configuration for a particular application depends on the mechanical requirements and operating frequency.

A radome that is electrically thin (less than 0.1 wavelengths) [4], as shown in Figure 3, will generally deliver good RF performance. This is because signal reflections at the free-space/dielectric boundary are cancelled out by out-of-phase reflections from the dielectric/free space boundary on the other side of the dielectric material. Figure 4 shows that signal losses are low and the net transmission from an electrically thin dielectric laminate is very high. Unfortunately, electrically thin radomes provide very little thermal insulation and are not suitable for locations with wide temperature extremes and a requirement for controlled temperatures.

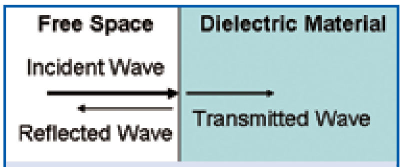

*Figure 2: When an electromagnetic wave hits the dielectric interface, part of the wave is transmitted through the dielectric material, and the rest is reflected.*

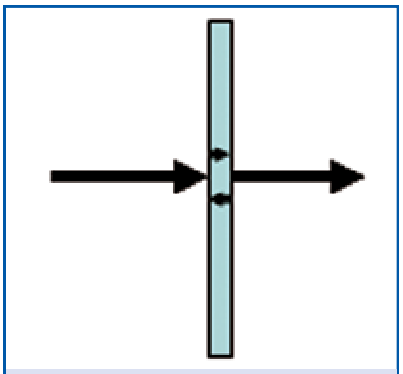

*Figure 3: In an electrically thin dielectric layer, reflections at the air/dielectric boundary are cancelled by the reflections on the other side of the laminate at the dielectric/air boundary, resulting in low-loss transmission of the incident wave.*

Another radome approach that works well is a configuration based on the half-wavelength-thick solid laminate shown in Figure 5. It is similar to the electrically thin configuration because the reflections cancel out. The wave travels 180° through the laminate, is reflected with a phase shift of -180°, and travels another 180° on the return trip to achieve the net 180° phase shift required for cancellation. Figure 6 shows the performance of the same laminate described in Figure 4 at higher frequencies (through 35 GHz) where it is 0.5 wavelengths thick.

An A-sandwich radome configuration consists of a low dielectric foam or honeycomb

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core sandwiched between two thin laminates as shown in Figure 7. Its operation is similar to the half-wavelength-thick solid laminate. However, it is 0.25 wavelengths thick because the reflection coefficients from the skins have the same amplitude and phase. The round trip for the reflection from the second skin is 0.5 wavelengths. The reflections, which are 180° out of phase, cancel (Figure 7).

A C-sandwich radome consists of three skin layers and two foam layers as shown in Figure 9. The thickness of each foam layer, and possibly the skins, can be tuned for optimal RF performance in the bands of interest. This can lead to many potential construction combinations that can provide good RF performance and high mechanical strength. C-Sandwich constructions provide better performance than A-sandwich radomes; however, the added complexity increases material and labor costs.

## Structural Support

Although radomes are used extensively on airframes and missiles, this section focuses specifically on support structures for terrestrial and shipboard systems. Ground and shipboard radomes can range in size from very small antenna covers to massive structures tens of meters in diameter. There are many methods to support the structure, each with strengths and limitations summarized in Table 1.

Self-supporting radomes are usually based on an A-sandwich configuration. They are made of rigid sections that are bolted or latched together. If phase delay and insertion loss through the seam is matched to the rest of the radome, the seam becomes largely invisible to the electromagnetic wave front. Unlike other radome types mention in this article, A-sandwich radomes require no air blowers to maintain pressure and are not dependant on electrical power to maintain their electro-magnetic or structural performance. A-sandwich radomes generally have lower overall operation and maintenance costs.

Inflatable radomes are made of electrically thin dielectric cloth. By being electrically thin, they are capable of achieving very low loss over wide bandwidths. The tradeoff for high performance, however, is that they require a constant supply of air. Inflatable radomes must be supported by internally generated air pressure which is supplied by air blowers or air compressors. In order to maintain adequate air pressure, inflatable radomes must be equipped with airlocks at all doors and a stand-by power supply to operate the blowers at all times and under all environmental conditions. Should the membrane suffer damage or if power is interrupted it's possible for the radome to deflate and collapse. Operating and maintenance costs for this type of radome usually exceeds those of all other radome types.

Metal space frame radomes support the window portion of the radome consisting of the electrically thin, half-wave, or A-sandwich configuration, often in the shape of a geodesic dome. The window portion typically has very low loss. However, signal blockage from the frame reduces system gain and reflects noise back into the system. Because the frame reflects and refracts the RF wave front, it increases sidelobe levels. A method used to prevent large sidelobes is the use of a quasi-random frame pattern. The quasi-random pattern is also used to minimize sidelobes for the other support structure types.

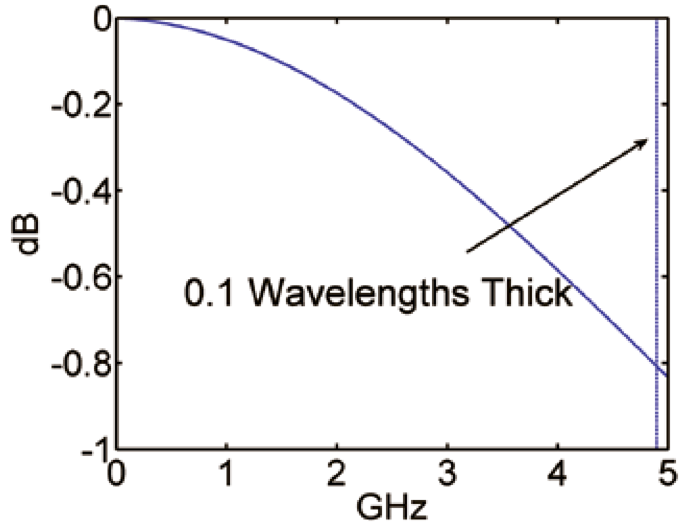

*Figure 4: The insertion loss through an electrically thin dielectric laminate at normal incidence is plotted here as a function of frequency. The laminate is 0.12 inches thick, has a dielectric constant of 4 and a loss tangent of 0.01. Loss increases with increasing frequency (and decreasing wavelength). When the thickness of the laminate is 0.1 wavelengths (at 4.9 GHz), the loss is 0.81 dB.*

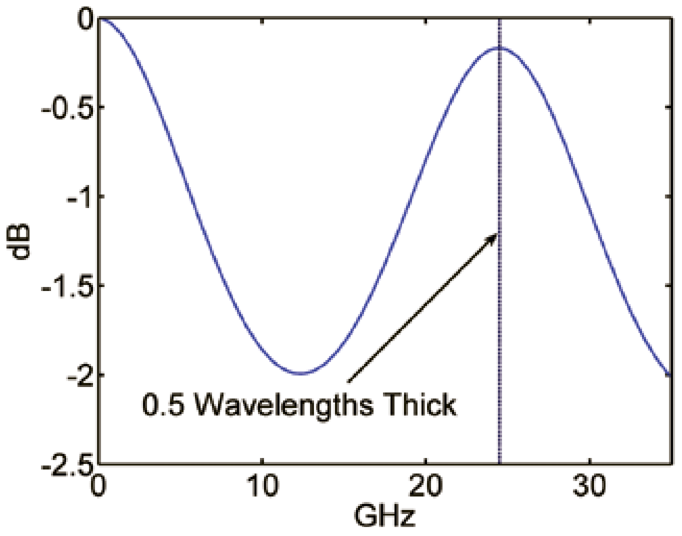

*Figure 6: The insertion loss of the laminate analyzed in Figure 4 is plotted here at higher frequencies. When the laminate material is 0.5 wavelengths thick, the reflections cancel and the net signal transmission is high.*

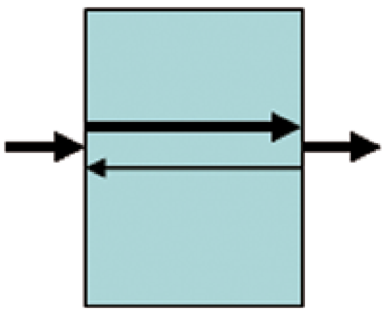

*Figure 5: In a half-wavelength-thick radome, the round trip of signals through and reflected by the laminate introduces a 360° phase shift. The reflections at each interface cancel because they are out of phase, resulting in high net transmission of incident signals.*

In contrast to metal space frame radomes, dielectric space frame radomes are supported by dielectric members which are somewhat electrically transparent. However, the wave front is phase delayed as it passes through the dielectric support, alternating between in and out of phase depending on frequency. If the delay is 180° out of phase with the phase of the incident signal, the energy that passes through the frame subtracts from the gain. This leads to a frequency dependant sinusoidal ripple in the insertion loss and the lost energy goes into the sidelobes. This makes dielectric space frame radomes best suited to systems that operate at less than 1 GHz.

Both types of space frame radomes usually require the use of air blowers or compressors in order to maintain and enhance the structural integrity of their thin membrane coverings during windy conditions. Failure to maintain positive pressure can result in membrane damage and

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failure.

### Impact of Incident Angle

All of the plots and explanations thus far show reflections at normal incidence. Typically, an electromagnetic wave hits the radome surface at an oblique angle, or in the case of a spherical radome, a continuous range of oblique angles. The transmission characteristics of the radome change with the wave incidence angle and polarization. Electric fields that are parallel to the plane of incidence have much higher transmission than fields that are perpendicular to the plane of incidence.

Aerodynamic radomes used on aircraft and missiles often see high incidence angles. This can result in large amounts of axial ratio degradation for circularly polarized antennas and higher insertion loss. Electromagnetic wave fronts from parabolic antennas located inside spherically shaped radomes see low incident angles at the center of the wave front. Out on the edges however the incident angle becomes higher. If the antenna illumination pattern is symmetric, and the antenna is placed at the center of the spherical radome, the symmetric shape of the radome cancels out axial ratio degradation from the oblique incidence angles seen by the antenna.

### Radome Performance Variables

A well-designed radome provides environmental protection with minimal effect on the RF performance of the antenna and system. Electrically, the main concern for the radome is its contribution of insertion loss. Insertion loss reduces the available signal, decreasing effective radiated power and G/T (the ability of the antenna to receive a weak signal). Radomes can also increase antenna sidelobes, resulting in interference with other communication systems, and increasing the likelihood of signal detection and interception from unintended observers. Radomes can also impact antenna polarization schemes, depolarizing circularly polarized antennas, for example. Depolarization is generally very small for spherical radomes, but can be severe for radomes with large incident angles such as those used on missiles or aircraft. Some other electrical effects of a radome on antenna performance include change in antenna beam width and shifting of the antenna boresight.

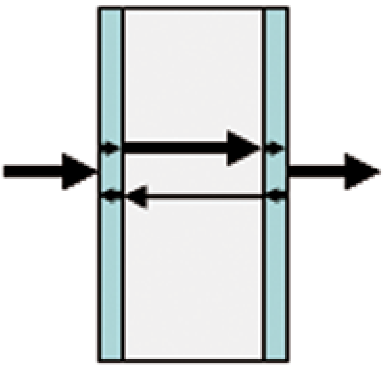

*Figure 7: An A-sandwich radome construction consists of a foam core with thin laminates on either side.*

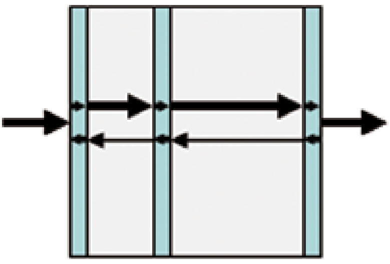

*Figure 9: C-sandwich configuration. Two layers of core material provide additional parameters to tune for multiband operation.*

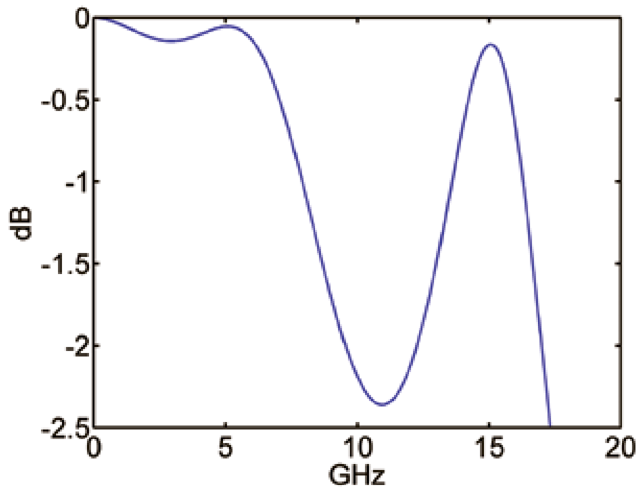

*Figure 8: Reflections of an A-sandwich radome are plotted versus frequency. The foam core is designed to be 0.25 wavelengths at 5 GHz, which provides maximum performance at <7 GHz (and 15 GHz where the phase shift is an odd multiple of 180°).*

*Figure 10: Hydrophobic surfaces cause water to bead, minimizing impact to RF performance under wet conditions.*

In addition to the effects of the radome material, nothing degrades radome performance more than a thin sheet of water. Water has a very high dielectric constant and loss tangent at microwave frequencies. Non-hydrophobic surfaces cause water to stick to the radome creating a thin film, which serves as a shield to RF transmission resulting in significant signal attenuation [5]. Well-designed radomes feature a hydrophobic surface that causes water to bead up and run off as shown in Figure 10. Even in high rain conditions, a radome with a hydrophobic surface has little additional attenuation [6].

In conclusion, a radome is often considered as an “afterthought” to an RF/microwave system but it is essential to overall system performance and lifetime cost. A well-designed antenna radome not only provides environmental protection that extends the operating lifetime of the antenna and its components, it also contributes to stable electrical performance over the lifetime of the system with reduced maintenance efforts and downtime, thus supporting reduced total cost of ownership.

### About MFG Galileo

*Located in Sparks Nevada, MFG Galileo is a leader in supplying composite radomes to the radar and satellite communications industry. They have been in business over 17 years and have radome installations on all seven continents. For more information please visit www.mfggalileo.com.*

### Radome Terms and Definitions

*Composite material* – A material that is made of multiple materials. The composite material combines strengths of multiple materials to produce a new material with better properties than the materials have individually.

*Electrically thin radome* – Single layer radome where the layer is less than 0.1 wavelengths thick

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**Table 1: Features and drawbacks of radome support configurations**

| | *Features* | | | | *Drawbacks* | | |
|---|---|---|---|---|---|---|---|
| **Radome Type** | **Can withstand >150 MPH winds** | **Electrically thin broadband performance** | **Tuned multiband performance** | **Provides thermal insulative properties** | **Requires constant positive pressure** | **Support frame adds significant loss** | **Notes** |
| **Self Supporting Sandwich** | X | | X | X | | | |
| **Inflatable** | X | X | | | X | | |
| **Metal Space Frame (MSF)** | X | X | X | | X* | X | |
| **Dielectric Space Frame (DSF)** | X | X | X | | X* | X | **Insertion Loss Ripple above 1 GHz** |
| **Solid Laminate** | X | | | X | | | **Single Band Tuning** |

** Thin fabric membrane radomes need positive pressure to prevent damage in high wind conditions.*

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at the frequency of interest.

*Half-wave radome* - Single layer radome where the layer is 0.5 wavelengths thick at the frequency of interest.

*A-sandwich* – A radome configuration consisting of a low dielectric core, with high dielectric skins on either side.

*C-sandwich* – A five-layer radome configuration with three skins having high dielectric constant, and two cores with a low dielectric constant.

*Gain* - The ratio of the power density of an antenna's radiation pattern in the direction of strongest radiation to that of a reference antenna. The ability to focus an RF signal.

*G/T* – Figure of merit for satellite antennas similar to signal to noise ratio. Stands for gain/temperature, where temperature is the noise temperature in Kelvin.

*Insertion loss* – Total energy loss due to reflection and absorption loss.

*Reflection loss* – Energy lost because it is reflected by the radome.

*Absorption loss* – Energy lost because it is absorbed and converted to heat due to dielectric loss.

## References

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[2] Balanis, C. A., Advanced Engineering Electromagnetics, John Wiley and Sons, New York, 1989, pp. 180-185.

[3] Skolnik, M., Radar Handbook, 2nd Ed., McGraw Hill, Boston, 1990, pp. 6.44-6.45.

[4] U.S. Department of Defense, "MIL-R-7705B - General Specification for Radomes," U.S. Government Printing Office, 1975, pp. 2.

[5] Anderson, I., "Measurements of 20-GHz Transmission Through a Radome in Rain," IEEE Transactions on Antennas and Propagation, Sept. 1975, pp. 619-622.

[6] Dietrich, F. J. and West, D. B., "An Experimental Radome Panel Evaluation," IEEE Transactions on Antennas and Propagation, November 1988, pp. 1566-1570.

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